Nuclear Instruments and Methods in Physics Research A 341 (1994) 481–483
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Performance of a MOPA laser system for photocathode research **

R.F.X.A.M. Mols *, G.J. Ernst

University of Twente, Department of Applied Physics, P.O. Box 217, 7500 AE Enschede, The Netherlands

A Nd:YLF laser system with frequency doubled output is described. Several aspects concerning energy and stability of the pulses will be discussed. The system consists of a CW mode locked Nd:YLF oscillator and two double pass amplifiers having a total small signal gain of about a million which means care must be taken to prevent self-oscillations Due to saturation effects the energy per micropulse is limited to 20 μJ, resulting in 8 μJ at the second harmonic frequency (526.5 nm). For the frequency conversion KTP type II is used. The short term timing stability was measured using a spectrum analyser and found to be less than 200 fs with a width of 450 Hz. The amplitude fluctuations over the 15 μs macropulse are determined by the saturation behaviour of the amplifiers and the shot to shot stability of the amplifiers. Third and fourth harmonic generation is under study.

1. Introduction

Photocathode injectors have proved to be excellent sources for high current low emittance electron beams, as needed for instance for FELs [1]. In the TEUFEL project [2] two stages are planned. In the first stage a 6 MeV accelerator will be used and a 50 period undulator of 1.25 m length with an undulator parameter $K = 1$ [3] which is supposed to lase at about 180 μm. Because an electron beam with a very high peak current, low emittance and a low energy spread will be used, at this wavelength a very high exponential gain will be obtained so that a SASE set-up can be used [4]. Due to the long wavelength the slippage will be about 25 ps which means that long electron pulses are needed.

In the second stage the electron beam will be accelerated up to 25 MeV using a racetrack microtron [5]. Using the same undulator but with 40 periods the resonance frequency will be about 10 μm. An optical resonator will be used with a length of only 1.85 m giving special design considerations for the focusing of the electron beam [6]. Because a microtron will be used the peak current is limited to about 75 A and since the slippage is small a short pulse is sufficient (10–20 ps).

In this paper the laser system used to illuminate the photo-cathode of the 6 MeV accelerator is described.

* Corresponding author.

** Sponsored by the Nederlands Centrum voor Laser Research (NCLR), the Technology Foundation (STW) and the Foundation for Fundamental Research on matter (FOM).

2. Pulse compression

The whole system is based on a CW ML Nd:YLF laser (Coherent Antares 76) giving 50 ps pulses at 81.25 MHz, being the 16th subharmonic of the 1.3 GHz and having a wavelength of 1053 nm. After second harmonic generation (SHG) the pulse will be about 40 ps long which is used for the first stage experiment. For the second stage however optical pulse compression is desired to obtain a low emittance, low energy spread electron beam. The pulse compressor used consists of an optical fiber, where new frequency components are generated due to self-phase modulation (SPM). The resulting pulse still has a frequency chirp which is partially compensated by using a negative dispersive path consisting of prism–grating pair in a four pass configuration. This set-up is schematically shown in Fig. 1 and the quantitative behaviour of such a pulse compressor from an optics designer point of view is discussed in ref. [7]. For the free electron laser experiment a fiber of 6 m length is used giving a compression of 2.5. This length is limited by the maximum average power onto the fiber. This power is limited to 2 W even though average powers as high as 4 W have been used. After a few hours the incoupling face of the fiber gets dark and the incoupling efficiency, at low powers up to 70%, reduces dramatically. The peak power onto the fiber for a 2 W average power beam is about 2 GW/cm^2 whereas a damage threshold for quartz is expected of about 100 GW/cm^2 for a 20 ps pulse. Improvement of the amount of power through the fiber can therefore be obtained by chopping the optical beam before incoupling. For the fiber length used it is estimated [7,9] that the threshold for stimulated Raman scattering

SSDI 0168-9002(93)E1195-4

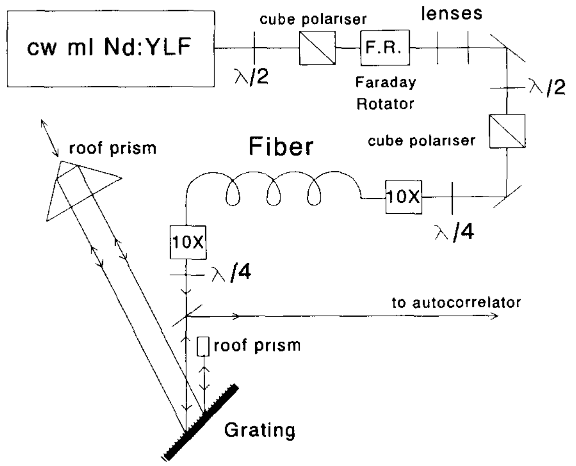

Fig. 1. Experimental set-up of the optical pulse compressor.

(SRS) is higher than 1.5 W. It is essential to operate the pulse compressor below this threshold because SRS gives rise to both amplitude and timing jitter as discussed in ref. [9]. The amplitude jitter as measured behind the pulse compressor is $0.10 \pm 0.01\%$ and the timing jitter is 170 ± 10 fs measured using the method described first by von der Linde [8].

3. Amplification

The energy per mode-locked pulse from either the pulse compressor or the laser is limited to about 10 nJ which is much less than the required energy of about 20 μJ. Therefore the pulses have to be amplified using Nd : YLF amplifiers. Since our pulses are longer than 10 ps, gain narrowing is not very important as long as the number of passes is limited to about five for 10 cm long laser rods.

In our current set-up, for the first phase of our project, the pulse compressor is not used and the light of the ML Nd : YLF laser is used directly. This continuous train is chopped using an acousto-optic modulator (AOM) to obtain the 15 μs long macropulses. The advantages of an AOM in comparison with the widely used electro-optic modulators (EOM) are amongst others the high damage threshold for the average power in the beam, typically more then 10 W for an AOM and 3 W for an EOM depending on the material used. Important is the infinite extinction ratio due to the fact that the beam which is used is being deflected under a different angle than the original beam, while using an EOM a polariser is used with an extinction ratio of typical 1 : 200. Two minor advantages are that the drive power of an AOM is very low and this device is relatively cheap. Our AOM has a rise and fall time of about 125 ns and has a scatter efficiency of 65%. Both these numbers depend on the exact focusing of the laser beam into the crystal and the scatter efficiency is limited by the available RF power of 2 W from our current driver. In general, an AOM is a good candidate for feedback purposes since the RF drive signal can be modulated by mixing the RF with an error signal of only a few volts, resulting in the required intensity fluctuations. This allows the electronics to be simple and fast. In our case of a macropulse of 15 μs the bandwidth of the feedback is less than 1 MHz due to the transit time of about 1 μs which is caused by the travelling time of the acoustic wave from the piezo crystal to the section where this wave interacts with the optical beam.

The amplifier set-up consists of two double pass amplifiers, one containing a 6 mm rod, the other one using a 7 mm rod. The small signal gain of the first rod is up to about 0.39%/cm while the second rod has a small signal gain of about 0.30%/cm. The difference in gain between the two rods, which are pumped with the same energy, is caused by the different volume of the rods. The increase of the energy density for the smaller rod is about 36%. The high gain means that in the design of the whole set-up care should be taken to prevent self-oscillations since the low signal gain of the whole system is about a million. Very small reflections at surfaces will result in lasing. If the two double passes are infinitely well isolated two amplifier set-ups have to be optimised, both with a 100% reflecting mirror on one side of the amplifier. This means, for a single pass gain of 50, that the other components may only reflect 0.04% back into the amplifier. Since the isolation between the amplifiers is not perfect even a better reduction of reflections is required. This isolation should be better than 1 : 1000 to avoid oscillations of the entire set-up. Methods used to reduce back-reflections in the individual chains are amongst others: the use of antireflection coated optics, misalignment of the components in a way that also multiple reflections

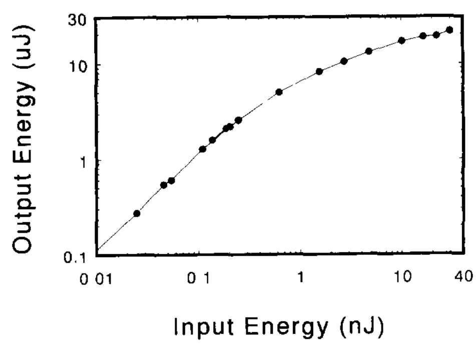

Fig. 2. The output energy per micropulse as a function of the input energy. In the region of interest of about 10 nJ input power already strong saturation takes place.

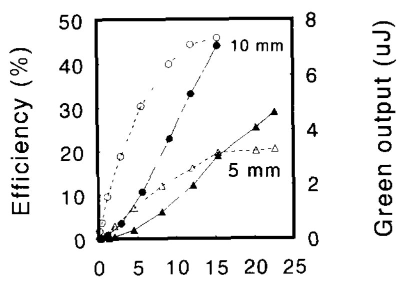

Fig. 3. Results of SHG using KTP crystals of 5 mm length (lower two curves) and 10 mm length (upper two curves). The open markers indicate the efficiency while the solid markers indicate the output at 526.5 nm.

are not fed back in the chain and the use of spatial filters.

The macropulse energy will not gain a factor of one million due to saturation. The energy after the first double pass is already at a level that saturation takes place immediately in the second double pass. This saturation leads to pulse reshaping since the first part of the macropulse has a much higher gain than the end. To obtain a flat macropulse the timing between firing the amplifiers and the macropulse is adjusted in order to have higher pumping during the latter part of the macropulse. In this way the flatness of the envelope of the macropulse is generally a few percent. The energy per micropulse obtained in this way is shown as a function of the input energy from the mode locked oscillator in Fig. 2. From this figure the saturation energy cannot be determined since no maximum amount of energy is gained from the medium.

4. Second harmonic generation

Since the photocathodes used are insensitive to IR radiation the laser light has to be frequency doubled to 526.5 nm. In our current set-up this is done using type II phase matching in a 5 mm and a 10 mm long KTP crystal. The results are given in Fig. 3. It shows that in this length and power region the conversion is almost linear with both length and power giving about a two times higher efficiency for the longer crystal. It should be noticed that the KTP length is limited by group velocity mismatch (GVM) which tends to broaden the pulse. Using a 10 mm crystal pulses can be frequency doubled down to 10 ps.

The whole frequency conversion part will be changed in order to generate 3rd and 4th harmonic. The SHG will be done using LBO type I because it can be used at non-critical phase matching so that an 18 mm long crystal can be used. It is expected to give efficiencies of more than 60%. Third harmonic generation (THG) will be obtained using a 15 mm LBO type II crystal. This length is limited by the walk-off of 0.53°. Fourth harmonic generation (FHG) will be generated using BBO type I. The walk-off angle in BBO is very large, therefore cylindrical focusing will be used. The length of the crystal is then limited by the GVM which is 5.86 ps/cm. Also KDP would be a good candidate for FHG but this material is hygroscopic. Using an 8 mm BBO crystal an efficiency of 22% has been obtained at LANL [10] for the conversion of 526.5 nm to 263 nm.

Acknowledgement

The authors like to thank James Early of Los Alamos National Laboratory for many fruitful discussions concerning the amplification schemes and the generation of harmonics.

References

[1] P.G. O'Shea et al., Nucl. Instr. and Meth. A 331 (1993) 62.
[2] G.J. Ernst et al., Nucl. Instr. and Meth. A 318 (1992) 173.
[3] J.W.J. Verschuur, G.J. Ernst and W.J. Witteman, Nucl. Instr. and Meth. A 318 (1992) 847.
[4] G.J. Ernst and J.C. Goldstein, Nucl. Instr. and Meth. A 318 (1992) 649.
[5] J.I.M. Botman et al., these Proceedings (15th Int. Free Electron Laser Conf., The Hague, The Netherlands, 1993) Nucl. Instr. and Meth. A. 341 (1994) 402.
[6] R.F.X.A.M. Mols, G.J. Ernst and J.I.M. Botman, Nucl. Instr. and Meth. A 318 (1992) 341.
[7] R.F.X.A.M. Mols and G J. Ernst, Opt. Commun. 94 (1992) 509.
[8] D. von der Linde, Appl. Phys. B 39 (1986) 201.
[9] R.F.X.A.M. Mols and G.J. Ernst, Opt. Commun. 99 (1993) 45.
[10] J.W. Early, private communication.